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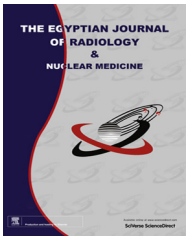

ORIGINAL ARTICLE

Multidetector computed tomography (MDCT) angiography of thoracic aortic coarctation in pediatric patients: Pre-operative evaluation

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KEYWORDS

Coarctation of aorta (CoA);
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Atrial septal defect (ASD)

Abstract *Objective:* The purpose of this study was to evaluate the reliability of 64-slice multidetector computed tomographic (MDCT) angiography in pre-operative assessment of coarctation of thoracic aorta of pediatric age groups using 64 multislice CT scanner.
Materials and methods: Twenty four patients with clinical suspicion of coarctation of the thoracic aortic anomalies who underwent both Doppler echocardiography and MDCT angiography were included in the study. MDCT angiography findings were compared with both Doppler echocardiography and surgical results.
Results: The overall sensitivity of the MDCT angiography for diagnosis of the extra-cardiac aortic anomalies was 100% which was higher than that of Doppler echocardiography (92%). The overall sensitivity of MDCT angiography for the assessment of cardiac defects was 85% which was lower than that of Doppler echocardiography (100%).
Conclusion: We concluded that MDCT angiography with multiplanar and three dimensional techniques can be considered the modality of choice for pre-operative assessment of coarctation of the thoracic aorta in pediatric patients.

1. Introduction

Coarctation of the aorta is a congenital malformation and typically a disease of childhood and early adulthood (1). Hypertensive vascular complications, cerebrovascular hemorrhage, aortic valve destruction, premature coronary artery disease and aortic aneurysms are seen in patients with unrepaired coarctation of the aorta. In addition, dissection or rupture of the aorta is a life threatening complication of coarctation of

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the aorta (2). Although the diagnosis of coarctation of the aorta can usually be made on clinical grounds, imaging is necessary to evaluate the exact anatomy of the lesion and to detect associated abnormalities. During the past decade, CT angiography has become a principal examination for the evaluation of aortic anomalies. Recently MDCT angiography has become a principal imaging modality for the evaluation of thoracic vascular anomalies because of its short acquisition time and high spatial resolution (3). MDCT angiography with multiplanar and three dimensional techniques is the non-invasive method of choice for assessing the morphology of coarctation of the aorta particularly to characterize the location, degree and length of the narrowing, presence of collateral circulation, relationship to the left subclavian artery and associated cardiovascular abnormalities. It is important to have accurate information about each of these parameters to devise surgical or interventional repair (4,5). Pediatric thoracic CTA doses quoted in the literature vary greatly from 1 to 2 mSv to more than 50 mSv (6,7). A variety of techniques have proved effective in lowering radiation exposure, including decreasing tube current, increasing pitch and table speed, avoiding multiphasic imaging, and minimizing scan coverage (8–10). Rotational tube current modulation, a form of automatic exposure control, can be used to further lower radiation exposure (11–13). This current study, therefore was designed to evaluate the reliability of 64-slice multidetector computed tomographic (MDCT) angiography for preoperative assessment of coarctation of the aorta in pediatric patients.

A 320-MDCT volume scanner allows axial volumetric scanning up to 16 cm in the *z*-axis in a single 0.35-second gantry rotation with no table movement. This scanner is alluring to pediatric radiologists because it offers the potential advantages of decreased scan durations, reduced motion artifacts, reduced need for sedation, and reduced contrast agent volume requirements. In addition, the lack of *z*-axis overranging, lack of overlapping helical rotations, and minimal penumbral overbeaming with volumetric scanning have the advantage of reducing patient radiation exposure (14).

Effective radiation dose for 320 MDCT volumetrically acquired ECG-gated pediatric cardiac CT angiography is lower than those published for conventional 16- and 64-MDCT scanners (14).

Low dose prospectively gated axial 256-slice CT angiography is a valuable tool in the routine clinical evaluation of infants with congenital heart disease providing a comprehensive three dimensional evaluation of the cardiac anatomy, including coronary arteries (15).

In the past decade, thanks to increasing computational power, statistical iterative reconstruction (IR) has become a hot research topic in CT, with a focus on noise suppression, artifact reduction, and dual-energy or energy-sensitive imaging. Some of these efforts are now under translation from bench to bedside. Similar to the filtered back projection (FBP) algorithm widely used In MDCT, IR is a method to reconstruct 2-D and 3-D images from measured projections of an object (16).

In response to these concerns and calls for dose reduction, CT vendors have developed several techniques to help maintain diagnostic image quality of studies acquired at a lower radiation dose. Automatic exposure control and hybrid iterative reconstruction, such as adaptive statistical iterative reconstruction (ASIR) and iterative reconstructive in image space, are two of the techniques aimed at reducing image noise (17).

2. Materials and methods

2.1. Patient population

Twenty four patients (13 males and 11 females) were included in this study, age ranges from 4 months to 12 years old. They are presented with clinical suspicion of coarctation of the aorta. Symptoms include dyspnea (n = 15), chest pain (n = 6), congestive heart failure (n = 5), headache (n = 4) and epistaxis (n = 2). Signs include upper extremities hypertension (n = 12), abnormal findings on chest X-ray (n = 5), weak femoral pulse and murmurs (n = 4) (Table 1). They all underwent Doppler echocardiography. These patients fulfilled the inclusion criteria of this study and composed our study sample. Each patient's parent was thoroughly asked about the detailed clinical history after reviewing the referring imaging request and laboratory findings. Exclusion criteria for CT are as follows: previous allergic reactions to iodine contrast media and sever renal insufficiency. According to the hospital policy, informed consent was taken and signed by the patient's parent and referring doctor.

2.2. Patient preparation

The patient was on fast for about 2–3 h before appointment due to the administration of contrast media in this examination. Hydration was recommended 4 h prior to the exam.

2.3. Sedation

Patients below 4 years were sedated; orally administrated chloral hydrate (50–100 mg/kg; maximum dose, 2000 mg) and I.V. administrated phenobarbital sodium (6 mg/kg; maximum dose 200 mg). The remaining patients cooperated without sedation.

3. Imaging technique

3.1. Contrast enhancement factors

Patients received 2 ml/kg of non-ionic contrast medium (300 mg/ml, omnipaque). In patients with anticubital catheter,

Table 1 Demographic criteria, age, sex, number and clinical presentation in 24 patients.

Variable	Frequency	Percentage
Age		
Range	4 m–12 yrs	–
Number	24	–
Sex	13 male	54
	11 females	45.8
Symptoms		
Dyspnea	15	62.5
Chest pain	6	25
Congestive heart failure	5	20.8
Headache	4	16.6
Epistaxis	2	8.3
Signs		
Upper extremities hypertension	12	50
Chest x ray abnormalities	5	20.8
Weak femoral pulse	4	16.6

contrast medium was injected with a power injector at a rate of 2–3 ml/s for a 22-gauge cannula and 3–4 ml/s for a 20-gauge cannula. Manual injection was used when the IV access was via a 23 and 24-gauge cannula placed in the dorsum of the hand or wrist. The scanning delay was determined with a bolus tracking technique. The examination initiated 4 s after attenuation of the region of interest positioned in the ascending aorta reached 150HU. A right arm injection was preferable to avoid artifacts from undiluted contrast media in the left brachiocephalic vein.

3.2. Technical factors

MDCT angiography examinations were performed using (light speed VCT) 64-slices spiral CT scanner. Patients were examined in supine position, scan extended from the root of the neck to the diaphragm. Imaging parameters are as follows: 100 kVp, 100–200 mA (varied automatically according to the body size). Collimation 16×1.25 mm, slice thickness 1.25 mm, slice interval 0.625 mm, pitch set automatically, reconstruction interval 0.625 mm.

The patients were referred to the radiology department for preoperative assessment of coarctation of the aorta by multidetector computed tomography (MDCT) angiography.

The radiologist was blind to the results of Doppler echocardiography.

All MDCT images were evaluated for the site, length and degree of coarctation of the aorta. The presence of additional cardiac defects such as atrial septal defects, ventricular septal defects and patent ductus arteriosus was evaluated.

Aortic coarctation was defined as greater than 25% decrease in vessel diameter, either focal or diffuse. The degree of stenosis was considered severe if the ratio of the coarctation diameter to the distal descending aortic diameter was less than 50%. The length of the coarctation was considered short if the length of the narrowed aortic segment was less than 5 mm and long if the length was more than 5 mm.

For three-dimensional images, the volumetric CT data were processed on a separate workstation with multiplanar reformatting (MPR), maximum intensity projection (MIP) and volume rendering (VR). Axial source images, the two and three dimensional data sets were evaluated for each of the 24 patients.

On the basis of Doppler echocardiography and MDCT angiography findings, surgery was performed for all patients. MDCT findings were compared with both Doppler echocardiography and surgical results.

4. Results

All aortic coarctations were classified as post-ductal type. The degree of stenosis was considered severe in 20 cases. The length of coarctation was short in 21 cases and long in 3 cases. The coarctation was located distal to the origin of the left subclavian artery in all cases (Table 5).

Whereas all coarctations (Figs. 1–5) were diagnosed correctly by multi-planner and three dimensional images with 100% sensitivity, two short coarctation (< 5 mm) were missed by axial images with 92% sensitivity (Table 4).

The site, degree and the length of the coarctation were reliably evaluated by multiplanar and three dimensional MDCT angiography images.

Surgical results were compared with MDCT findings and Doppler echocardiography (Tables 2 and 3).

Coarctation of the aorta was associated with additional cardiac anomalies in 13 cases. Three cases had atrial septal defects (Fig. 2d), 4 cases had ventricular septal defects (Fig. 1c) and 6 cases had patent ductus arteriosus (Table 5). The diameter of the patent ductus arteriosus ranged from 2 to 4 mm.

All cases of patent ductus arteriosus (Fig. 4b) were correctly diagnosed by both MDCT and echocardiography with overall sensitivity 100% (Tables 2 and 3).

One case of small ASD and one case of small VSD respectively were missed by MDCT but all cases of ASD and VSD were correctly diagnosed by Doppler echocardiography (Tables 2 and 3). The overall sensitivity of MDCT for assessment of cardiac defects was 85% which was lower than that of Doppler echocardiography (100%).

Table 2 MDCTA versus surgical findings in 24 patients of coarctation of the aorta (CoA).

Findings	MDCTA	Surgical
Coarctation of aorta	24	24
ASD	2/3	3/3
VSD	3/4	4/4
PDA	6/6	6/6

Table 3 Echocardiography versus surgical findings in 24 patients of CoA.

Findings	Echocardiograph	Surgical
Coarctation of aorta	22/24	24
ASD	3/3	3/3
VSD	4/4	4/4
PDA	6/6	6/6

Table 4 MDCTA findings of CoA and PDA.

Findings	Axial images	MPR	V.R.
Aortic coarctation	22/24	24	24
PDA	6/6	6/6	6/6

Table 5 Features of the 24 patients with coarctation of the aorta.

Vascular anomalies	ASD	VSD	PDA	Collateral vessels	Length of COA	Site of COA	Degree of COA	No
Double SVC1 aortic arch hypoplasia 1	3	4	6	15	Short 21 Long 3	Distal to LSCA cases	Sever 20 moderate 4	24

Figure 1 Multiplanar (A) and (B) images showing coarctation of the aorta distal to the left subclavian artery (curved arrows). Multiplanar (C) image showing VSD (straight arrow). Multiplanar (D) image showing internal mammary artery collaterals (small arrows).

MDCT showed associated vascular anomalies such as double superior vena cava (Fig. 2e) and hypoplasia of the aortic arch in one case and the aberrant right subclavian artery in two cases.

Collateral vessel formation was noted in 14 cases. Hypertrophied internal mammary artery was noted in 10 cases (Fig. 1d).

Beyond the cardiovascular system, MDCT depicted extracardiovascular lesions in 5 patients had pneumonia and 3 patients had atelectasis.

5. Discussion

Several imaging modalities have been reported in the evaluation of thoracic aortic anomalies. Because of its ability to provide both anatomic and hemodynamic information, conventional angiography remains the gold standard for pre-therapeutic of patients with aortic coarctation. It allows pressure gradient measurement across the coarctation, visualization of the collaterals and assessment of associated cardiac malformation, however this technique is invasive and enhances the risk for complication imposed by the coarctation (18).

Multi-detector computed tomography has several advantages versus conventional angiography, especially for children. Commonly, there is no need for sedation and general anesthesia. It has been successfully applied to children 4 years of age and above because they can easily adjust to the instructions. Low doses of sedatives can be used for smaller or agitated children. In uncooperative cases, scanning is performed during few seconds of calm. The short scanning time reduces motion artifacts, and image quality is not affected at all. Because of the fast scanning, MDCT is preferable when there is a severe illness or life-threatening situation. Also, it presents minimal invasive mortality and morbidity risks (19,20). Contrary to conventional angiography, potential interventional complications (dissections, occlusion, bleeding, etc.) are absent. It is easily applied in the case of bleeding diathesis. Conventional angiography has the disadvantage of taking a long time, being invasive and requiring anesthesia in the pediatric population. However unlike angiography, additional information, such as pressure curves and oxygen saturation data, cannot be derived from a MDCT examination (19,20). In addition to displaying vascular anatomy, Thoracic CT angiograms provide information about both airway and lung parenchyma, which is important in patients who have thoracic vascular anomalies. Three dimensional images allow excellent display of vascular anomalies that can be used as vascular road map by surgeon. CT angiography is a preferable modality of diagnosis for arterial disease as an alternative to conventional angiography (3).

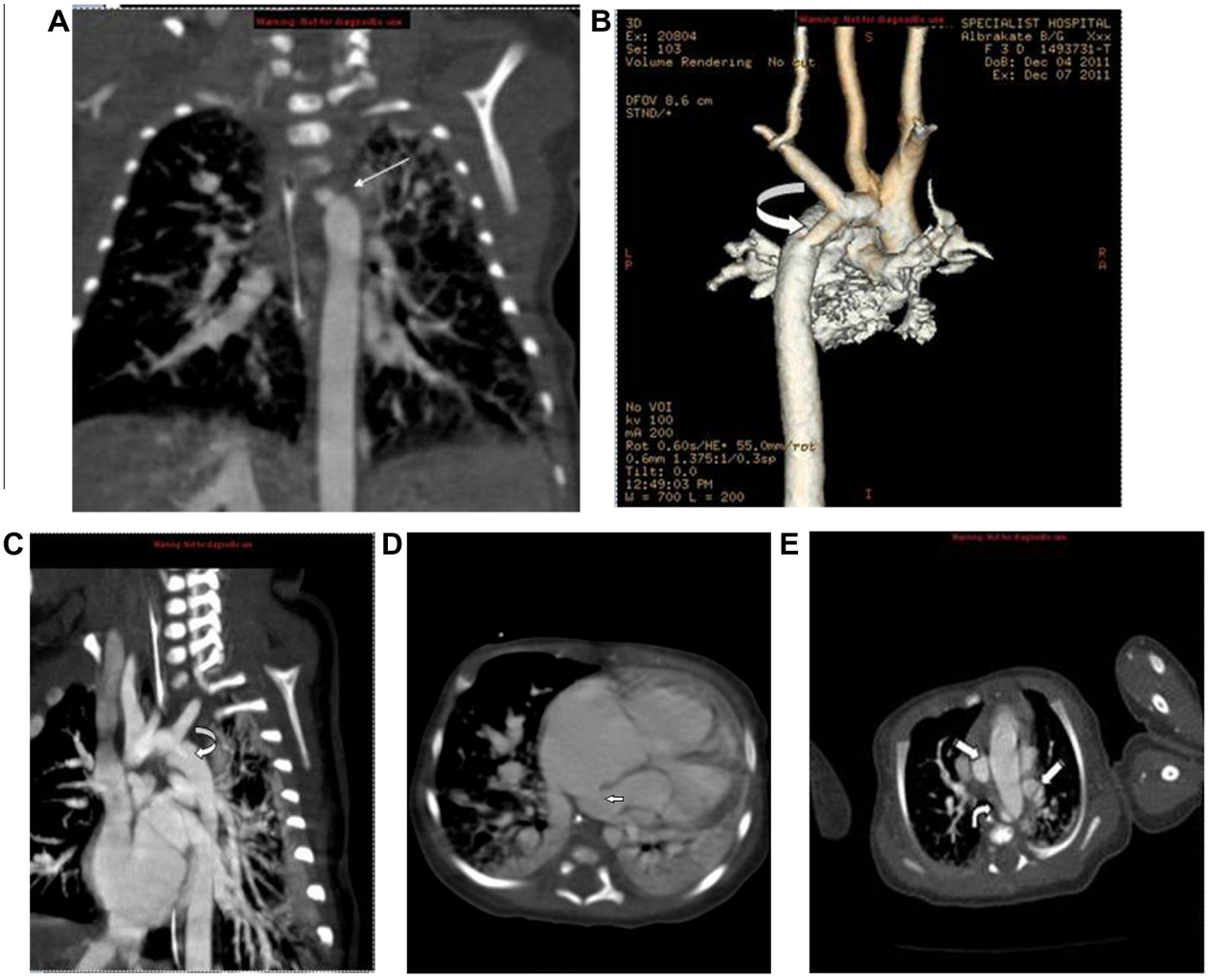

Figure 2 Multiplanar (A) and (C) images showing aortic coarctation (straight and curved arrows). Volume rendering image (B) showing aortic coarctation (curved arrow). Axial (D) image showing ASD (straight arrow). Axial (E) image showing double SVC (straight arrows).

Doppler echocardiography is currently the first imaging modality used, identifying the location and severity of the coarctation and has the advantages of a noninvasive estimation of the pressure gradient across the narrowing. But it is sometimes difficult to obtain good visualization of the site of coarctation because of a poor acoustic window and the long distance between the transducer and the isthmic region (21). In this study two coarctations were missed by Doppler echocardiography.

Before the introduction of MDCT technology, magnetic resonance imaging (MRI) was frequently used for the assessment of congenital thoracic vascular anomalies because of multiplanar capability. Contrast enhanced MR angiography is, for the most part, sufficient for evaluation of the aorta and its branches, whereas cine MRI and phase contrast MRI allow assessment of the hemodynamic significance of the coarctaion as well as cardiac and valvular function (21,22).

When multiplanar and three dimensional post-processing techniques became available, the role of CT in the assessment of thoracic vascular anomalies changed. MDCT has changed not only the imaging evaluation approach to thoracic aortic anomalies but also challenged the role of conventional angiography (23–26).

MDCT has gained increasing acceptance as an alternative to MRI in the screening of vascular anomalies. Compared with MR angiography, CT angiography has the advantage of the ability to acquire high spatial resolution in a shorter acquisition time that means a reduced need for sedation and less intensive anesthetic management (26).

During sedation of critically ill-patients, the open and non-magnetic environment around a CT scanner facilitates monitoring and resuscitation if necessary. The speed of CT examinations enables the maintenance of thermal stability, which is critical in the care of neonates, more feasible than with MR examinations (26). CT provides information about both the lung parenchyma and bony structures that are not evaluated accurately by MRI. CT can be performed immediately post-operatively without risk in patients with any type or location of metallic fragments such as stents or surgical clips and there is no contraindication for patients with pacing systems (26).

Compared with MR angiography, MDCT angiography has the advantage of the ability to acquire high spatial resolution in a shorter acquisition time. In addition volume rendered and multiplanar reconstructions are better for MDCT angiography data display than MRI (27).

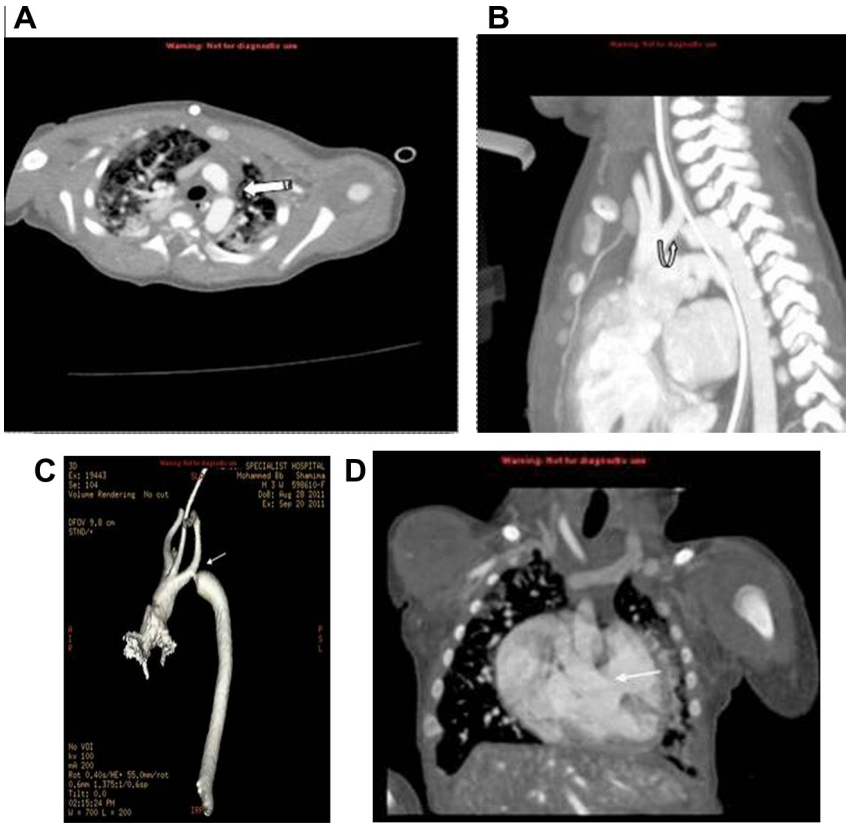

Figure 3 Axial (A), multiplanar (B) and volume rendering (C) images showing aortic coarctation distal to the left subclavian artery (straight and curved arrows). Multiplanar (D) image showing VSD (straight arrow).

MDCT with multiplanar and three dimensional techniques provide morphologic images of coarctation of the aorta and its relationship to the arch vessels as well as demonstrating collateral circulatory pathways (4,5). But it is not useful for visualizing the aortic gradient or small cardiac malformation (4). In this current study, the overall sensitivity of MDCT for the assessment of cardiac defects was 85% which was lower than that of Doppler echocardiography (100%). These results are in agreement with Hu et al. (4) in their study done on 2008 for assessment of coarctation of the aorta in young children and also with Turkvatan et al. (28) in their study done on 2009 for assessment of coarctation of the aorta.

This current study compared the accuracy of axial CT, multiplanar reformats and 3D volume rendered images in the evaluation of coarctation of the aorta in pediatric patients. The results of this study show that in the evaluation of coarctation, multiplanar and 3D volume rendered images performed slightly better than axial images. For the diagnosis of coarctation, sensitivities were 92% for axial, 100% for multiplanar and 100% for volume rendered images.

Previous studies have described the role of axial and three dimensional volume rendering in the diagnosis of mediastinal vascular anomalies (3,4). Recently, a study concerning with CT angiography and three-dimensional reconstruction in young children with CoA showed the diagnostic sensitivities of CoA were 87.5% for axial and 100% for multiplanar and three dimensional volume-rendered images (4). In another study, the results were consistent with this former study (3). Previous and these current studies reported that the MDCT angiography is a non-invasive, feasible technique for assessing aortic coarctation.

Radiation exposure is important in the pediatric population because children are considered to be more sensitive to ionizing radiation than adults, and they have longer life expectancy. The main disadvantage of MDCT is radiation exposure. Computed tomography protocols are associated with a known increase in the risk of future malignancy (29). According to these findings, dose-saving algorithms are very important in reducing radiation exposure and should be used in every imaging modality, especially during childhood. These algorithms include shorter scan time, lower tube currents, increased table speed or pitch, and increased speed of gantry rotation. As with all pediatric CT, mAs must be adjusted for patient size (30,31). In this current study, we used the parameters of 100 kVp and 100–200 mAs (varied automatically according to body size) to provide optimal quality images without any significant loss of diagnostic data.

The small number of patients and lack of conventional angiography and magnetic resonance angiography to assess the accuracy of the MDCT data are the major limitations of the present study. Because of the radiation burden and invasiveness, we were not able to compare this technique with conventional angiography. MRI provides not only the advantage of imaging without radiation, but also functional assessment. In particular, flow measurements are of interest to identify relevant collateral circulation (32). However, in MRI the

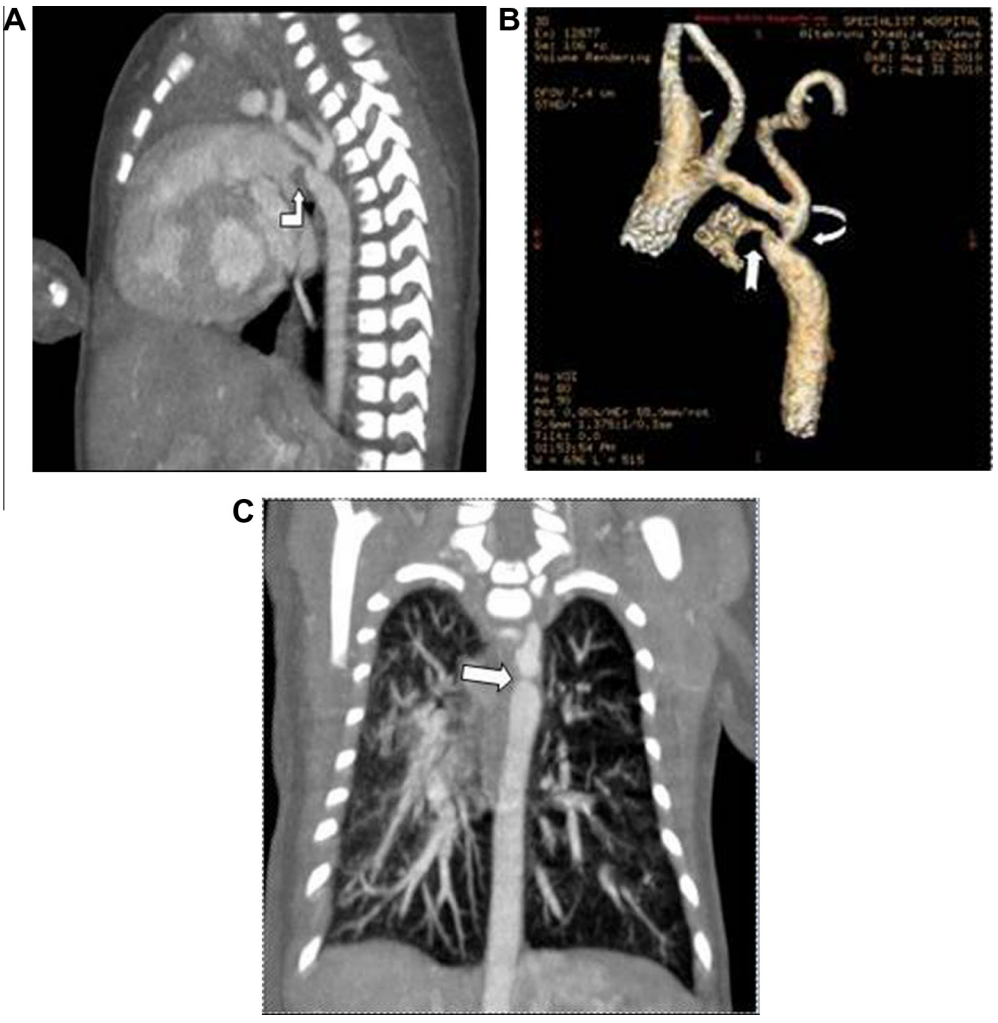

Figure 4 Multiplanar (A) and (C) images showing aortic coarctation (curved and straight arrows). Volume rendering image (B) showing coarctation of the aorta (curved arrow) and small PDA (straight arrow).

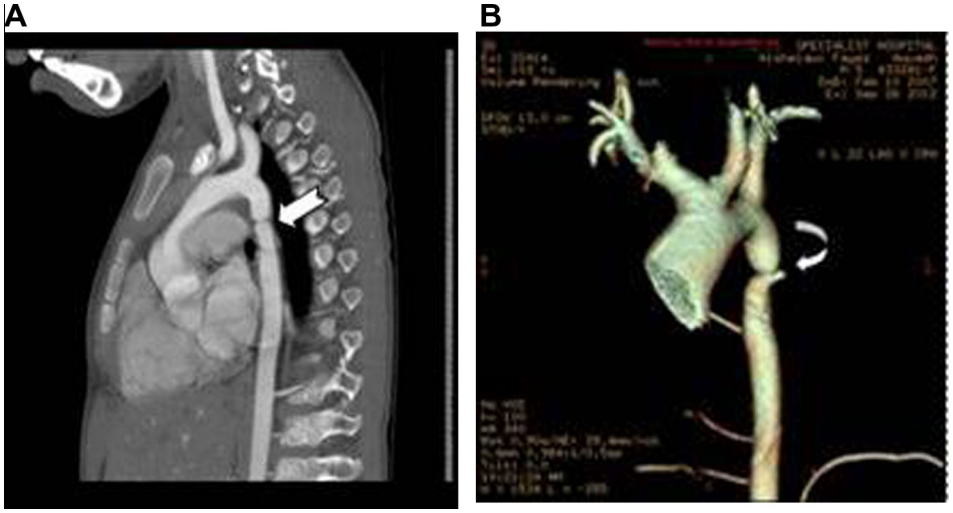

Figure 5 Multiplanar (A) image showing coarctation of the aorta (straight arrow) and volume rendering image (B) showing aortic coarctation (curved arrow).

scanning time is longer than in MDCT which may require prolonged sedation and may be difficult to perform in seriously ill children.

In conclusion, MDCT angiography is the method of choice for preoperative assessment of coarctation of the aorta in pediatric patients and young adults. It can easily identify the precise location and the degree of the coarctation and its relationship with the branch vessels. The presence of associated aneurysm or dissection and origin and course of collateral vessels can also be depicted with MDCT. Because axial images may be insufficient for evaluation of short coarctation, multiplanar and three dimensional images are needed in the assessment of coarctation of the aorta.

Prior studies with iterative reconstruction techniques in phantoms and adult patients have shown promise for dose reduction while maintaining or even enhancing image quality at lower radiation doses (17). Prakash et al. (33) reported a 25.1% dose reduction with use of abdominal CT and ASIR reconstruction in adults when compared with FBP-based image reconstruction. Similar dose reduction with ASIR has also been reported for chest CT in adults when compared with the FBP technique as reported in prior studies in adult patients, we found that objective image noise was lower with ASIR than with FBP reconstruction of pediatric chest and abdominal CT images. A recent phantom study for noise power spectrum analysis has shown that ASIR is associated with lower image noise than FBP at all spatial frequencies (17).

Sarabjeet et al. (17) reported that the chief implication of our study is that it is feasible to apply a hybrid iterative reconstruction technique in children undergoing low-dose chest and abdominal CT. The hybrid iterative reconstruction enables substantial dose reduction with pediatric body CT while maintaining acceptable image quality compared with the conventional FBP technique. They concluded that ASIR based protocols reduce image noise in lower radiation dose pediatric chest and abdomen CT examinations when compared with FBP. (17).

Vorona et al. (34) used 64 MDCT machine and published 22% reduction in the average CT dose index volume and a 24% reduction in the average dose length production (DLP) when using 20% ASIR, at no significant detriment to subjective image quality in pediatric patients.

The 320-MDCT volume scanner has theoretic advantages of increased temporal resolution, decreased scan duration, and decreased motion artifacts compared with conventional 16-MDCT and non-dual-source 64-MDCT scanners. Volume acquisitions can potentially decrease radiation exposure during cardiac imaging, compared with helical acquisitions, because of the lack of overranging, minimal overbeaming, and avoidance of low-pitch helical scanning with volume acquisition. Diagnostic-quality imaging for cardiac CTA using this volume CT scanner has been shown recently in adults and children (14).

Nie et al. (35) concluded that prospective ECG-gated dual source CT (DSCT) with a low radiation dose is a valuable technique in the diagnosis of coarctation of the aorta in infants and children.

Gao et al. (36) stated that prospective ECG-triggering DSCT angiography was associated with a significant lower effective radiation dose than retrospective protocol while maintaining image quality for diagnosis. Prospective ECG-triggering DSCT angiography could be used as a very important diagnostic tool in infants with complex congenital heart disease.

Conflict of interest

The authors have no conflict of interest to declare.

References

(1) Fixier DE. Coarctation of the aorta. Cardiol Clin 1998;6:561–71.
(2) Westaby S, Parnell B, Pridie RB. Coarctaion of the aorta in adults. J Cardiovasc Surg 1997;28:124–7.
(3) Lee EY, Siegel MJ, Hildebolt CF, et al. MDCT evaluation of thoracic aortic anomalies in pediatric patients and young adults. Comparison of axial, multiplanar and 3D images. AJR 2004;182:777–84.
(4) Hu XH, Huang GY, Pa M, et al. Multidetector CT angiography and 3D reconstruction in young children with coarctation of the aorta. Pediatr Cardiol 2008;29:726–31.
(5) Utak O, Karaca M, Bayturan O, et al. Coarctaion of the aorta evaluation with 64-row multislice computed tomography. Int J Cardiol 2006;111:169–71.
(6) Tsai IC, Chen MC, Jan SL, et al. Neonatal cardiac multidetector row CT: why and how we do it. Pediatr Radiol 2008;38:438–51.
(7) Taylor AM. Cardiac imaging: MR or CT? Which to use when. Pediat Radiol 2008;38(Suppl. 3):S433–8.
(8) Siegel MJ. Multiplanar and three dimensional multi-detector row CT of thoracic of thoracic vessels and airways in the pediatric in the pediatric population. Radiology 2003;229:641–50.
(9) Haramati LB, Glickstein JS, Issenberg HJ, et al. MR imaging and CT of vascular anomalies and connections in patients with congenital disease: significance in surgical planning. Radiographics 2002;22:337–47.
(10) Leschka S, Oechslin E, Husmann L, et al. Pre- and postoperative evaluation of congenital heart disease in children and adults with 64-section. Radiographics 2007;27:829–46.
(11) Goo HW, Park IS, Ko JK, et al. CT of congenital heart disease: normal anatomy and typical pathological conditions. Radiographics 2003;23:S147–65.
(12) Goo HW, Suh DS. Tube current reduction in pediatric non-ECG-gated heart CT by combined tube current modulation. Pediatr Radiol 2006;36:344–51.
(13) Lerner CB, Frush DP, Boll DT. Evaluation of a coronary-cameral fistula: benefits of coronary dual-source MDCT angiography in children. Pediatr Radiol 2008;38:874–8.
(14) Podberesky Daniel J, Angel Erin, Yoshizumi Terry T, et al. Radiation dose estimation for prospective and retrospective ECG-gated cardiac CT angiography in infants and small children using a 320-MDCT volume scanner. AJR 2012;199:1129–35.
(15) Haung MP, Liang CH, Zhao ZJ, et al. Evaluation of image quality and radiation dose at prospective ECG-triggered axial 256-slice multi-detector CT in infants with congenital heart disease. Pediatr Radiol 2011;41:858–66.
(16) Jingyan Xu, Mahadevappa Mahesh MS, Tusi Benjamin MW. Is iterative reconstruction is ready for CT. Am Coll Radiol 2009;6:274–6.
(17) Sing Sarabjeet, Mannudeep K, Anuradha S, et al. Radiation dose reduction with hybrid iterative reconstruction for pediatric CT. Radiology 2012;263:537–46.
(18) Godart F, Labort G, Devos P, et al. Coarctaion of the aorta: comparison of aortic dimensions between conventional MR imaging, 3D MR angiography and conventional angiography. Eur Radiol 2002;12:2034–9.
(19) Goo HW, Park IS, Ko JK, et al. CT of congenital heart disease: normal anatomy and typical pathologic conditions. Radiographics 2003;23 [Spec No: S147-65].

(20) Pappas JN, Donnelly LF, Frush DP. Reduced frequency of sedation of young children with multisection helical CT. Radiology 2000;215:897–9.
(21) Didier D, Saint-Martin C, Lapiere C, et al. Coarctaion of the aorta: pre and postoperative evaluation with MRI and MR angiography, correlation with echocardiography and surgery. Int J Cardiovasc Imaging 2006;22:457–75.
(22) Kellenberger CJ, Yoo SJ, Buchel ER. Cardiovascular MR imaging in neonates and infants with congenital heart disease. Radiographics 2007;27:5–18.
(23) Goo HW, Park IS, Ko JK, et al. Computed tomography for the diagnosis of congenital heart disease in pediatric and adult pateints. Int J Cardiovasc Imaging 2005;21:347–65.
(24) Leschka S, Oechslin E, Husmann L, et al. Pre and postoperative evaluation of congenital heart disease in children and adults with 64-slice CT. Radiographics 2007;27:829–46.
(25) Schertler T, Wildermuth S, Teodorovic N, et al. Visualization of congenital heart vascular anomalies using multidetector row computed tomography, two and three dimensional postprocessing. Eur J Radiol 2007;61:97–119.
(26) Oguz B, Haliloglu M, Karcaltincaba M. Pediatric multidetector CT angiography: spectrum of gongenital thoracic vascular anomalies. Br J Radiol 2007:376–83.
(27) Oddone M, Granata C, Vercellino N, et al. Multimodality evaluation of the abnormalities of the aortic arches in children: techniques and imaging spectrum with emphasis on MRI. Pediatr Radiol 2005;35:947–60.
(28) Turkvatan A, Ozdemir PA, Olcer T, et al. Coarctation of the aorta in adults: preoperative evaluation with multidetector CT angiography. Diagn Interv Radiol 2009;15(4):269–74.
(29) Kalra MK, Maher MM, Toth TL, et al. Strategies for CT radiation dose optimization. Radiology 2004;230:619–28.
(30) Daniel JC, Stevens DM, Cody DD. Reducing radiation exposure from survey CT scans. AJR Am J Roentgenol 2005;185:509–15.
(31) Frush DP. Thoracic cardiovascular technique and applications. Pediatr Radiol 2009;39(Suppl.):464–70.
(32) Fitoz S, Unsal N, Tekin M, et al. Contrast enhanced MR angiography of thoracic vascular malformation in children. Int J Cardiol 2007;123:3–11.
(33) Prakash P, Kalra MK, Kamhadakone AK, et al. Reduction abdominal CT radiation dose with adaptive statistical iterative reconstruction technique. Invest Radiol 2010;45:202–10.
(34) Vorona GA, Zuccoli G, Sutcavage T, et al. The use of adaptive statistical iterative reconstruction in pediatric head CT: a feasibility study. AJNR 2013;34:205–11.
(35) Nie P, Wang X, Cheng Z, et al. The value of low-dose prospective ECG-gated dual source computed tomographic angiography in the diagnosis of coarctation of the aorta in infants and children. Clin Radiol 2012;67:738–45.
(36) Gao Y, Lu B, Hou Z, et al. Low dose dual-source CT angiography in infants with complex congenital heart disease: a randomized study. Eur J Radiol 2012;81:780–95.